SMITHSONIAN INSTITUTION

ASTROPHYSICAL OBSERVATORY

OPTICAL SATELLITE-TRACKING PROGRAM

Carried out under Grant Number NsG 87

from the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Semiannual Progress Report No. 16

January 1 through June 30, 1967

Project Director: Fred L. Whipple

CAMBRIDGE, MASSACHUSETTS, 02138

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HIGHLIGHTS

From a theoretical description of the behavior of the upper atmosphere, it is now possible to determine atmospheric temperatures and densities at all points around the globe between 120 and 1000 km.

A total of 49 hours of mutual observation of flare stars by Jodrell Bank, CSIRO, and the Baker-Nunn network was accomplished.

Computer programs for the 1968 Smithsonian Standard Earth are being developed.

As of June 1, 1967, 3332 synthetic simultaneous observation pairs have been made.

A technique for observing star occultations by satellites has been developed. The system accuracy should be of the order of star-position accuracy.

It has been found that, contrary to some recent suggestions, the diurnal bulge does migrate seasonally with the sun and has a shape similar to that in earlier models.

During the period of this report, the Baker-Nunn camera network made 33,846 observations from 75,023 predictions. One-hundred thirty-five Moonwatch teams reported 8934 observations of 267 satellites, a new record.

Operation of the K-50 camera in Shiraz terminated. The station at Villa Dolores acquired the K-50 camera formerly at Curaçao, along with a BC-4 camera and associated equipment operated by the U. S. Coast and Geodetic Survey. The Baker-Nunn station at Debre Zeit was formally opened by H. I. M. Haile Selassie I on February 10.

A total of 15,282 precise reductions were made by the Photoreduction Division. The Division also completed a general-purpose plate-reduction program, and a new automatic reduction program was made operational.

The Baker-Nunn system-wide average timing uncertainty was reduced from ± 672 to ± 367 μsec.

Between January and June, 959 laser range measurements were obtained, bringing the number of range observations to about 2000 since the installation of the experimental laser system. A prototype laser system has been ordered for installation at Mt. Hopkins.

It is now possible to discuss observations of a comet or asteroid made over an indefinite period of time and to include the effects of the perturbations by all the major planets.

DATA ACQUISITION

SATELLITE-TRACKING AND DATA-ACQUISITION DEPARTMENT

Normal Operations

The Satellite-Tracking and Data-Acquisition Department continued normal operations by tracking satellites as assigned by the National Aeronautics and Space Administration and as needed to meet the requirements of the Observatory research program.

Operational statistics. Tables 1 and 2 provide statistics on operational results for the first half of 1967 compared to the first half of 1966, and successful observations from individual observing stations.

Launch support. We provided launch support for the early orbital determinations of Intelsat 2-F2, TOS B, OSO E1, ATS B, TOS C, San Marco B, ERS 18, ERS 20, ERS 27, UK E, and EGRS 9.

The Baker-Nunn camera at the Tokyo Astronomical Observatory and the cooperating U.S. Air Force Baker-Nunn cameras at Johnston Island and Edwards AFB successfully photographed and confirmed the fourth-stage apogee motor firing that inserted the Intelsat 2 F2 satellite into synchronous orbit over the Pacific Ocean. The Japan and Johnston Island photographs were simultaneous.

Simultaneous observations. The cooperative program to photograph satellites simultaneously with the Air Force Baker-Nunn stations at Cold Lake, Canada, Edwards AFB, California, Oslo, Norway, and Johnston Island was continued. SAO observers spent short periods at the Johnston Island, Oslo, and Cold Lake sites to assist in coordinating the program.

A cooperative effort with the National Space Research Agency of France was informally arranged with SAO Baker-Nunn cameras observing the French Satellites D1C and D1D.

Stations. On February 18 the SAO K-50 camera in Shiraz terminated operations, having obtained sufficient data to complete the geodetic tie with the Baker-Nunn site at Debre Zeit, Ethiopia, and the K-50 camera site in Athens, Greece.

On April 21 the Curaçao K-50 camera completed operations and was shipped to Villa Dolores, Argentina, to begin a program of observations with the new Baker-Nunn camera site at Comodoro Rivadavia, Argentina.

TABLE 1

COMPARISON OF OPERATIONAL RESULTS

January – June 1966, 1967

Month	Number of Predictions 1966	Number of Predictions 1967
January	12,628	10,980
February	10,445	9,476
March	12,526	13,452
April	13,502	12,534
May	13,745	14,831
June	12,158	13,750
Total:	75,004	75,023

Month	Number of Successful Observations 1966	Number of Successful Observations 1967
January	6,028	5,389
February	4,639	4,704
March	6,765	5,895
April	6,284	5,415
May	7,416	6,720
June	6,285	5,723
Total:	37,417	33,846

TABLE 2

SUCCESSFUL OBSERVATIONS BY INDIVIDUAL TRACKING STATIONS

January-June 1966, 1967

Station	Number of Successful Observations	
	1966	1967
New Mexico (SC-1)	4,053	3,826
South Africa (SC-2)	3,310	3,274
Spain (SC-4)	3,520	3,480
Japan (SC-5)	1,053	1,136
India (SC-6)	3,098	2,874
Peru (SC-7)	3,026	1,700
Iran (SC-8)	3,484	**
Curaçao (SC-9)	3,300	**
Florida (SC-10)	2,058	3,046
Villa Dolores, Argentina (SC-11)	3,361	**
Hawaii (SC-12)	3,395	1,876
Australia (SC-23)	3,759	4,694
Ethiopia (SC-28)	*	2,674
Brazil (SC-29)	*	1,373
Comodoro Rivadavia, Argentina (SC-31)	*	3,893
Total:	37,417	33,846

*The stations in Ethiopia, Brazil, and Comodoro Rivadavia, Argentina, were not operating during this period.

**The stations in Iran, Curaçao, and Villa Dolores, Argentina, were not operating during this period.

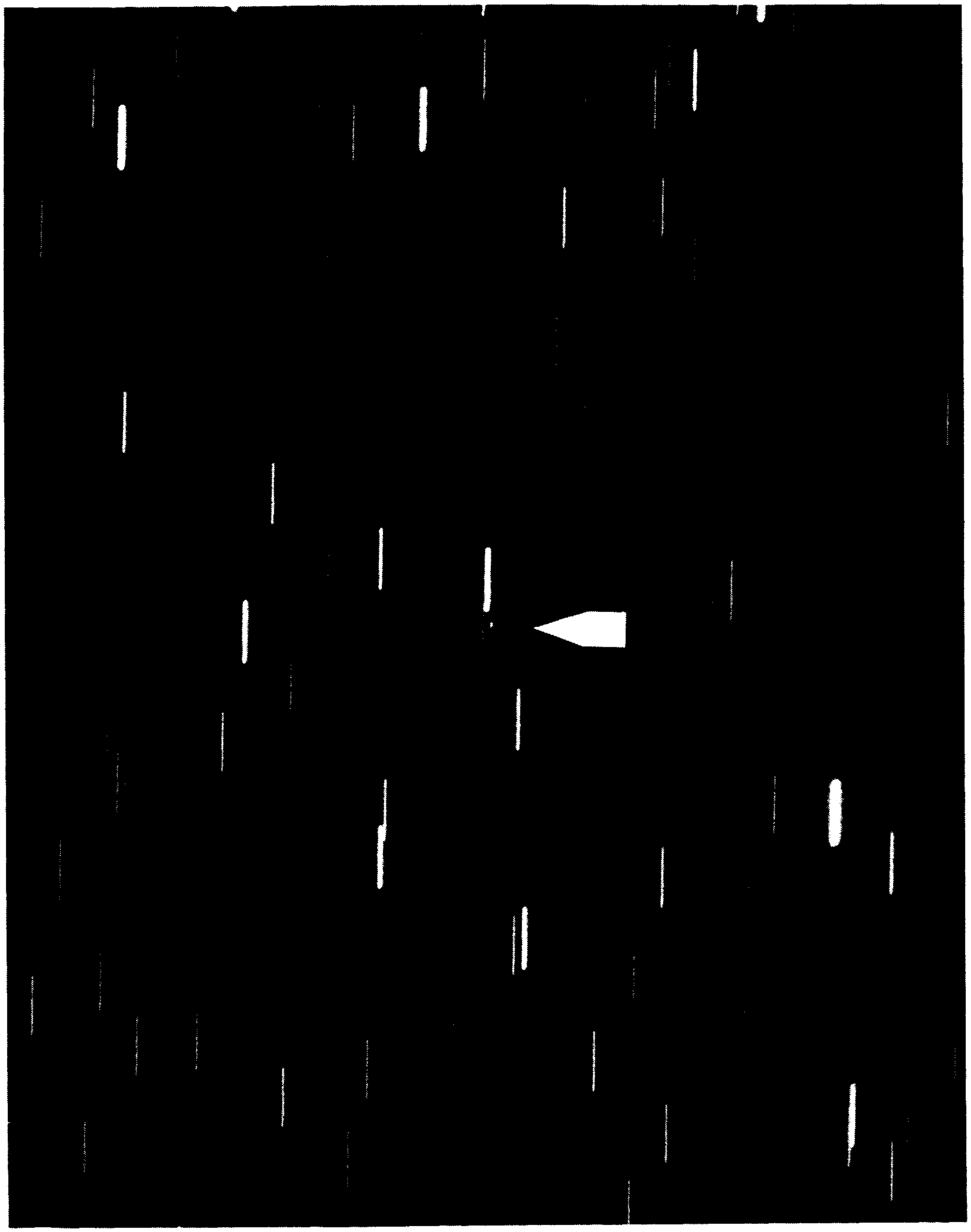


Figure 1. Photograph of the Applications Technology Satellite (ATS B) taken with the Hawaii Baker-Nunn camera on February 8, at $12^h40^m48^s$; exposure time, 30 sec. The approximate position of the ATS-B satellite is 36,370 km above the point -150° W longitude, 0° latitude. The range from the satellite to the station is 37,080 km.

The modified K-50 camera was moved from Athens to Dionyssos, Greece, early in June, in order to take advantage of better observing conditions.

The Debre Zeit, Ethiopia, station was formally opened by H. I. M. Haile Selassie I on February 10.

A Coast and Geodetic BC-4 camera and Doppler equipment were located in June at SAO's station in Villa Dolores, Argentina, under NASA sponsorship. The location was made possible through NASA's use of the SAO cooperative agreement dated March 16, 1962, with the Government of Argentina.

Special observations. Comet Seki 1967b was photographed during February for positional data.

During February and May photography of flare stars YZCMI and BD minus 8 degrees 4352B was carried out in conjunction with a cooperative observing program with the Jodrell Bank and the CSIRO Australia radio telescopes.

Engineering Support

Station and camera maintenance. After being cleaned and tested at Perkin-Elmer Corporation, a spare corrector cell replaced the Spain corrector cell, which was badly etched and beyond responding to field cleaning. With the minor refurbishing of the corrector cell originally associated with the former Air Force spectrograph located at Kwajalein, two corrector cells are now available for Baker-Nunn camera support.

All nine protective windows for the Baker-Nunn corrector cells have been received. Eight have been placed in storage until mating with the cells can be accomplished; a ninth is installed in the Comodoro Rivadavia camera.

The design of a modification of the Baker-Nunn camera film-transport mechanism that reduces the film frame size to approximately a $13° \times 5°$ field of view has been completed. A prototype installation made at the New Mexico station is in routine use. Production of the final model for installation at all stations is in progress. Considerable savings in film and processing costs are anticipated with the new film format, which is capable of being quickly changed back to the original $30° \times 5°$ field of view when conditions require it.

The drafts of two definitive technical manuals have been prepared to assist system maintenance, training, and quality control. One treats the Baker-Nunn camera and the other details photographic processing requirements of the Baker-Nunn system.

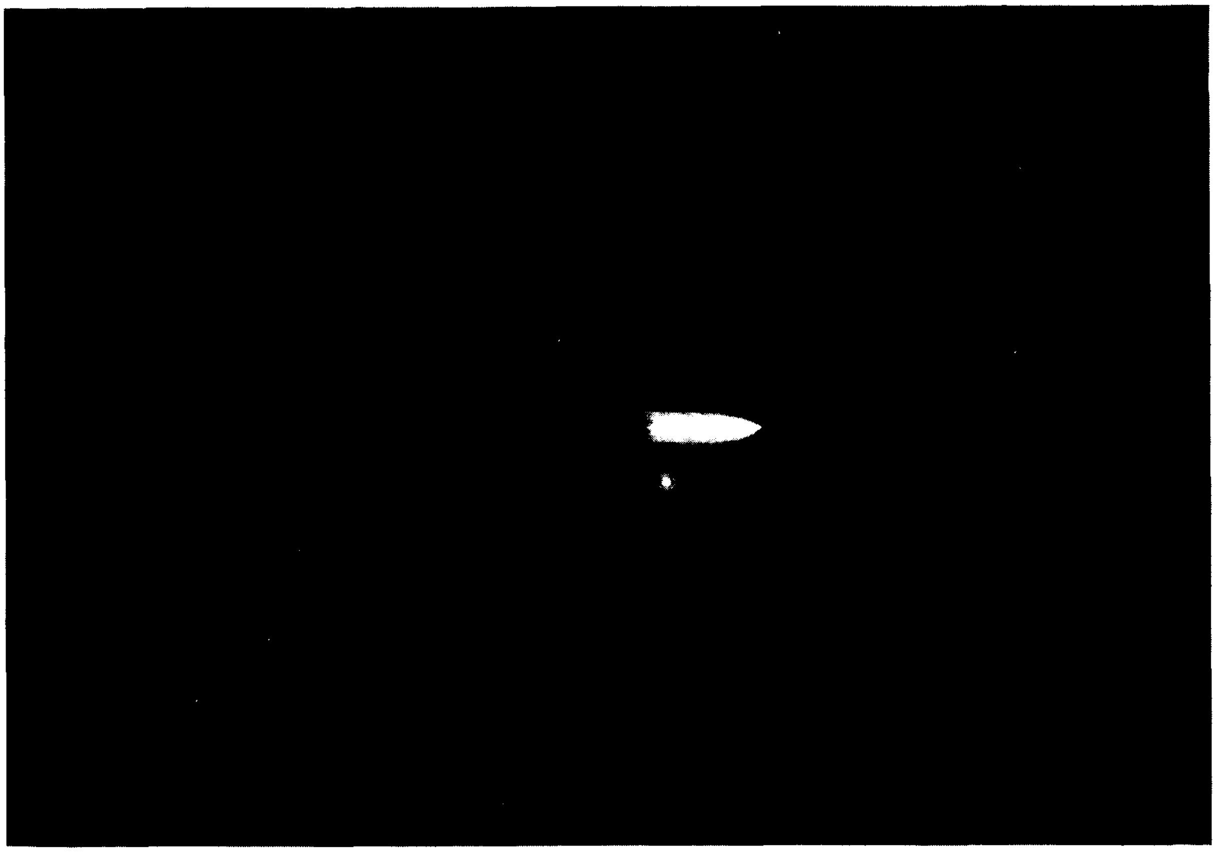


Figure 2. Photograph of Surveyor 3, launched from Cape Kennedy at 07^h05^m April 17, taken with the Florida Baker-Nunn camera; cycle rate, 4 sec/cycle, two transports per cycle; exposure time, 0.4 sec. The camera was operated at full aperture. The photograph shows the rocket crossing the constellation Cygnus (the bright star is Deneb 53) and shows the fanning of the exhaust gases.

Precision timing system. The Baker-Nunn system-wide average timing uncertainty was reduced from ±672 to ±367 μsec measured against the National Bureau of Standards' Universal Approximation time scale. All stations except India, which we have not yet been able to set with a portable clock, demonstrated maximum timing uncertainties lower than ±700 μsec. Three stations, Florida, New Mexico, and Hawaii, are keeping uncertainties lower than ±185 μsec.

Portable-clock comparisons were made at eight observing stations, six using SAO portable clocks and two under cooperating agreements with the Naval Observatory and the Coast and Geodetic Survey. In addition, time-setting trips were made between the SAO master clock in Cambridge and the Naval Observatory, the National Bureau of Standards, NASA Goddard, and Paris, France, Observatory clocks to ensure traceability of SAO timing data to any of these agencies.

A study was made to determine the future time-setting capability required by 100-μsec timing, and the means available to develop this capability. As a result, a portable rubidium clock is being procured that will be able to set field clocks within ±5 μsec of the Cambridge master clock. Further study of 100-μsec timing resulted in an outlined work plan for achieving this goal by January 1968.

Routine timing data were assembled from the National Bureau of Standards, the Naval Observatory, and the Cambridge monitor. This information was then used to notify observing stations of irregularities and to apply precise corrections to film times.

Electronic maintenance. Ten loop antennas were constructed and sent to observing stations with an aim to improving VLF time-signal reception and to reducing receiver sensitivity to atmospherics.

Geodetic camera development. Chopper-shutter performance has been standardized and calibrated. A new gross shutter design has been completed and the prototype is being constructed for installation on the modified K-50 cameras at Villa Dolores, Argentina, and Greece.

Laser Activities

Routine laser ranging on retroreflector-equipped satellites continued at the Organ Pass, New Mexico, laser facility. Some of the first range measurements acquired on the two French laser satellites were made in March by the New Mexico laser team. Table 3 shows the number of precise range measurements made per month on the retroreflector-equipped satellites GEOS A, BE B, BE C, D1C, and D1D.

Negotiations were completed for the three major prototype laser components and contracts for them were placed in early 1967. The equipment, which includes the static pointing pedestal, a laser transmitter, and a telescope photoreceiver and should be able to obtain returns in daylight, is scheduled for delivery about August 1, 1967. The equipment will be installed on Mt. Hopkins, Arizona.

TABLE 3

LASER RANGE MEASUREMENTS (1.5-m RESOLUTION)

January through June 1967

January	147
February	58
March	89
April	67
May	358
June	240
Total:	959

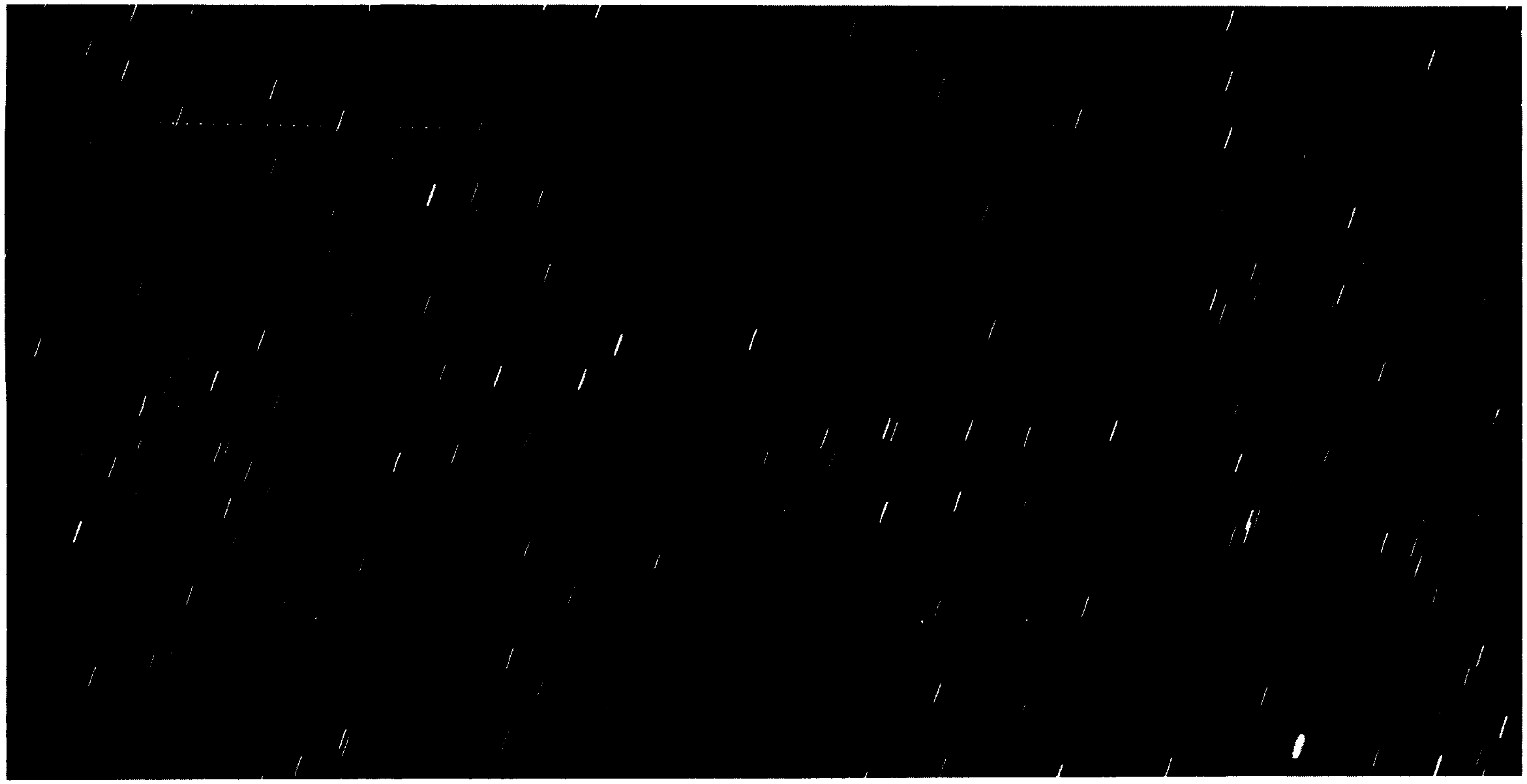


Figure 3. Photograph of UK E showing the sequence of solar glints reflected from the echelon mirrors mounted on the spacecraft body; exposure time, 15 sec. Taken with the Australia Baker-Nunn camera on May 14.

A proposal for the evaluation of a prototype laser satellite-tracking system (P 100-4-67) was submitted to NASA/OART in early May. The evaluation period for the prototype laser will commence in August when the system is delivered.

Moonwatch

There are now 135 Moonwatch teams with registered site numbers in 24 countries. With new teams in the United Kingdom and Holland, this is an increase of 14 since the last half of 1966.

In the first 6 months of 1967, 8934 observations of 267 satellites were reported, this being another record.

The standard of accuracy continues to improve. Analysis of observations of SAO satellites received in the last half of 1966 shows that there are now some 20 teams capable of making observations comparable in accuracy to Baker-Nunn field-reduced observations. Such observations are of value in orbit correction. On several occasions, Moonwatch observations have contributed significantly to the maintenance of the orbits of certain "difficult" satellites.

Steady and increasing interest continues to be shown in the Low-Perigee Program.

Predictions of satellite decays continue to be sent to appropriate teams, and the air pilot patrol has enrolled many new airlines.

The increased work involved in handling the observations has made it necessary to program some of the statistical work of the Division for the computer. This is being done with the help of the Data-Processing Department.

Predictions to the teams have been improved by issuing interim corrections to the ephemerides. The computation of ephemerides for the Australian and New Zealand teams by Adelaide Moonwatch is proceeding smoothly and has been largely responsible for increasing the useful output from these teams.

Figure 4. Baker-Nunn camera photograph from Japan of Intelsat 2-F2 apogee motor firing, taken on January 14. All exposures are 0.4 sec; times given are center exposure times.

Frame number	Time (UT)	Remarks
1	$10^h 11^m 35^s$	2 sec after ignition
2	10 11 37	
3	10 11 39	
4	10 11 41	
5	10 11 43	
6	10 11 45	
7	10 11 47	
8	10 11 49	Engine burnout
9	10 11 51	
10	10 11 53	
11	10 11 55	
12	10 11 57	
13	10 11 59	
14	10 12 01	
15	10 12 03	
16	10 12 05	
17	10 12 07	
18	10 12 09	
19	10 12 11	
20	10 12 13	

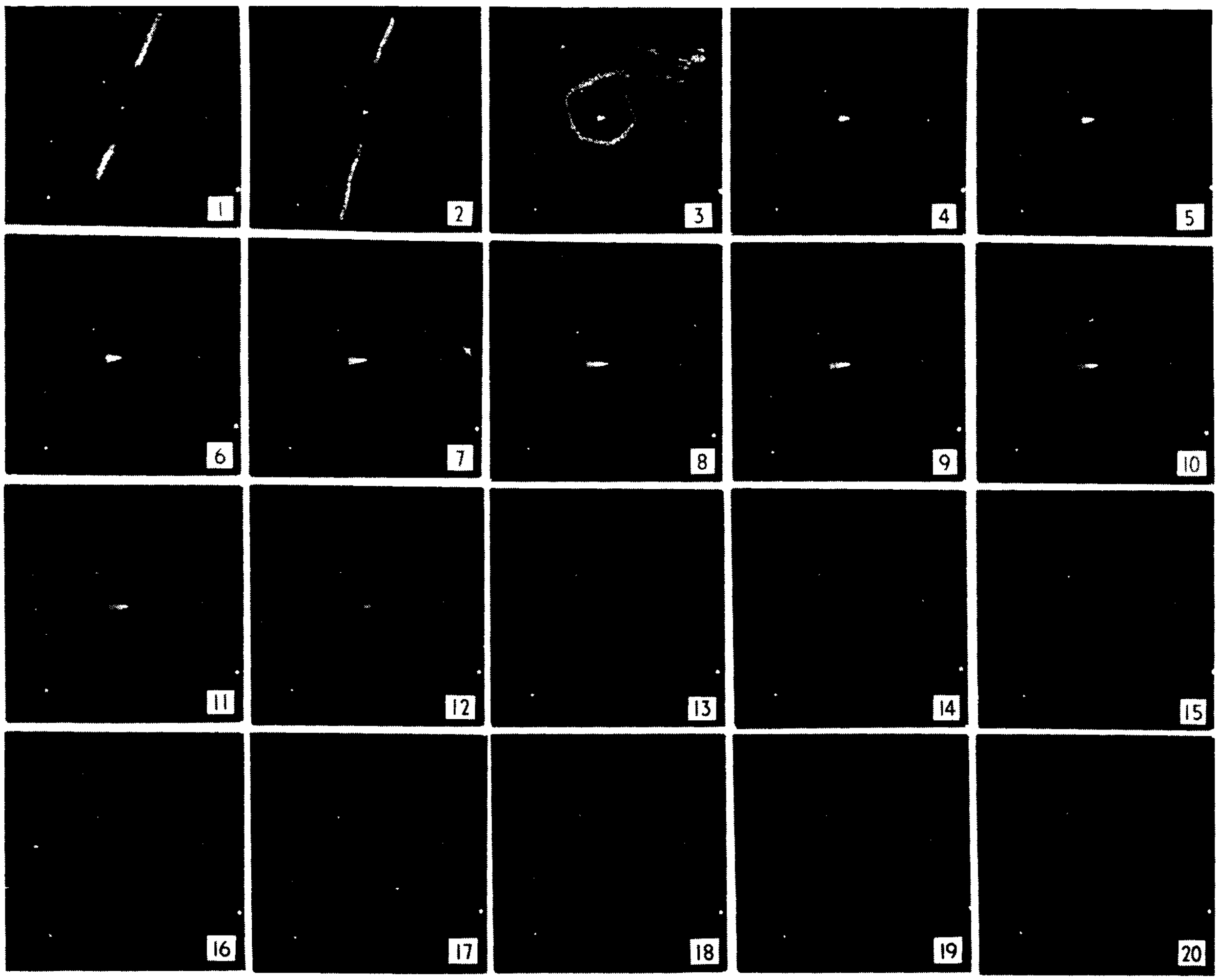


Figure 4.

COMMUNICATIONS

A 100-wpm teletype circuit tie-line between 60 Garden Street and 185 Alewife Brook Parkway has been established; among other purposes it will afford instantaneous communications for the upcoming OGO-D satellite launching. Through local patching facilities the circuit can be connected with any of several machines, resulting in immediate contact with NASA and other interested agencies.

Progress has been made in the construction of proper facilities for the new DCS Autodin (Defense Communications System, Automatic Digital Network) circuit. Final approval for the facility is expected within the very near future, and equipment installation will begin immediately thereafter. For approximately 16 months we have been operating on the DCS circuit through the facilities of the 1st Naval District Communications Center (COMONE) in Boston, via a 100-wpm tie-line circuit. The DCS network is used for transmittal and receipt of teletype traffic with observing stations in Spain, Japan, Hawaii, Ethiopia, and Greece plus many other observatories and cooperating agencies throughout the world. The use of this circuit results in substantial savings.

SAO is negotiating for the acquisition of adequate transmitter and receiver equipment for the observing station in Natal, Brazil, with plans to establish a radio-teletype circuit between the Natal station and the NASA station near Lima, Peru. SAO intends for the Natal station to be included on the NASA Communications (NASCOM) network. At the present, NASA's Peru station handles traffic via radio-teletype to and from our observing station in Arequipa, Peru, and via long-established and reliable circuits between Peru and SAO in Cambridge.

Several avenues have been investigated regarding the procurement of appropriate communications equipment for the Greece observing station, which moved from Athens to a mountain area near Nea Makri in April. The DCS network is now used to the Naval Communications Station in Greece and from there via Telex to the National Technical University in Athens, where messages are picked up by station personnel. Our intention is to provide UHF or other appropriate communications equipment and to establish a circuit between the Naval Communications station and the observing station. We shall continue, in any case, to communicate with the Greece station via the DCS network, at least as far as the Naval station.

DATA PROCESSING

DATA DIVISION

Operational Satellite Tracking

The Data Division supplied weekly tracking predictions to the Baker-Nunn, Moonwatch, and laser stations. Simultaneous predictions were sent to the modified K-50 geodetic cameras at Iran, Netherlands Antilles, and Greece, on the Echo-1, Echo-2, and PAGEOS-A satellites.

The Baker-Nunn stations performed backup observing on six NASA launches and one reentry.

The cooperative observing program with NORAD resulted in the Observatory providing tracking support on seven different objects in the past 6 months, and the Air Force Baker-Nunn cameras supporting the Observatory in its simultaneous program by tracking as many as five satellites in any 1 month.

A total of 40 satellites were tracked by the Baker-Nunn cameras during the first half of 1967 at the request of NASA, the Observatory's scientists, and other agencies. Orbital elements, field-reduced and photoreduced observations, predictions, long-range forecasts, and auxiliary data continue to be provided to the following agencies: Tokyo Astronomical Observatory, University of California, U.S. Coast and Geodetic Survey, Department of Defense, Langley Research Center, Bell Telephone Laboratories, Air Force Cambridge Research Laboratories, University of London, Raytheon Corporation, GIMRADA, and the National Center for Space Studies (CNES) in France.

A new method of high-density predicting for certain satellites was put into operation to implement the geodetic work.

The cooperative observing program with the Royal Radar Establishment at Malvern, England, and the European network of 17 stations continued through this period. Echo-1, Echo-2, and PAGEOS-A balloons were tracked in this program.

The Observatory is participating fully in the National Geodetic Satellite Program using the PAGEOS-A balloon.

A cooperative effort of 3 month's duration was carried out on the BE-B, BE-C, GEOS-A, D1C, and D1D laser satellites with the SAO and Air Force Baker-Nunn cameras, the SAO laser, the Goddard laser, and the laser system of France all participating. Preliminary results appear to be very good.

Star Catalog

Seven copies of the SAO Star Catalog on magnetic tape were sold in this period, bringing the total to 55 since 1963. The catalogs are sold at cost for $50.00 per copy, and the revenue is credited to the cost of operations.

Printed copies of the catalog were distributed to a very small number of applicants. About 400 copies are still for sale at the GPO from a total stock of 1200.

Star charts have been distributed to Baker-Nunn stations and to Moonwatch teams. A questionnaire distributed to about 600 schools and colleges indicated that about 1200 sets should be published.

Solar Data

Data on 8-, 10-, and 20-cm solar fluxes are received and tabulated, and resumés are sent once a month to subscribing parties.

Geomagnetic planetary indices are received and computed every 2 weeks, with subscribing parties receiving reports once a month.

A daily check on solar flares and magnetic storms is made to inform inquirers on solar activity.

Timing Data

Atomic time and UT data are received from time services in Paris, London, Washington, Tokyo, and Ottawa.

Polar-motion data are received from Paris and Tokyo.

PREDAT

Since its inception in January 1967, PREDAT, the Precision Central Section of the Data Division, has issued three bulletins, on Purpose, on Polar Motion, and on Star Charts.

New Star Catalog

Preparations have been made to receive the newest southern sky catalog (Ann. Cape Obs., vol. 21) on magnetic tapes from the U.S. Naval Observatory. A program to compare and incorporate this new material into the SAO Star Catalog is being written.

PHOTOREDUCTION DIVISION

Progress

The Film Control Section received and cataloged 32,283 Baker-Nunn films, 1,289 geodetic camera (K-50) plates, and 120 plates from the Royal Radar Establishment's camera in Malvern, England.

The reduction of a previously received batch of Malvern plates was completed. This effort resulted in 124 simultaneous observations made with SAO Baker-Nunn stations. A total of 15,282 precise reductions were completed.

The new automatic reduction program, written by Mr. I. G. Campbell and Mr. Dick Poland, was made operational (in a CDC 6400 version) in May. Using this program, an individual can now select the reference stars to be used, measure the frame in question, and let the computer determine which stars were measured, look up their coordinates in the SAO Star Catalog tape, and then perform the required reduction—all in a single computer run. Under the former system, the computer selected the stars to be measured on one run; then, after the measurement had occurred, the reduction was made in a second run. The elimination of a computer run in our process has had the immediate result of improving operational efficiency. A second benefit is that individuals can select more desirable reference configurations, since they are able to account for varying sky conditions more easily than the computer can.

Mr. David Arnold has completed a general-purpose program for the reduction of the various types of astrographic plates that the Division is called upon to measure. This program will be used in the coming months in the reduction of K-50 plates, Malvern plates, and a variety of plates from the European Geodetic Network.

In January a solid-state digitizing system was installed, to digitize measurement information from the comparators. It has shown a lower failure rate in comparison with the system it replaced.

We are continuing our joint effort with the Satellite-Tracking and Data-Acquisition Department for the improvement of the quality of films produced by the SAO network. Mr. Robert Yorke has distributed an updated outline of the requirements for precise reduction for use by field personnel. In addition he has begun a program of retraining for field personnel visiting Cambridge.

Plans

According to latest estimates, the digitization of our microdensitometer should occur during July 1967.

Our major effort during the coming months will be oriented toward the reduction of data for use in the next SAO Standard Earth computations.

We will perform an analysis of our reduction system to determine whether improvements can be made in timing or positional accuracy.

PROGRAMMING DIVISION

The Programming Division is responsible for the development of computer programs for all phases of the satellite-tracking program, for the operation of existing computer programs, and for development work in applied mathematics required to achieve these objectives. The computer programs now use almost exclusively a Control Data 6400.

Equipment Studies

Display system. A feasibility study is being conducted on the use of a microfilm printer-plotter.

New Equipment

The CDC 6400 was purchased during this report period as an extension of the grant year 1967 funds. A letter of intent has been forwarded to Control Data Corporation for advance scheduling and price commitment for a new central computer 6604, with an expected delivery date of November 15, 1968.

Computer Systems and Systems Programming

A remote terminal has been installed and is operating on a low-speed basis. We are now in the process of upgrading this terminal at 60 Garden Street to high-speed operation.

Many modifications were made to the current operating system (Scope 2.0). Work has progressed satisfactorily on the new system (Scope 3.0), which is now being used on a limited basis.

Programs

SCROGE. This program produces operating schedules for the tracking stations, based on satellite orbital elements. Further improvements have been made, such as the method of selecting regular predictions and the timing of long runs.

Simultaneous SCROGE. The simultaneous selection process has been expanded so that any number of satellites can be processed together. This eliminates conflicts at the stations concerned.

Standard Earth. Work is continuing on this project.

Tesseral harmonics. This program has been modified and has been reduced in field length by overlaying.

DOI (Differential Orbit Improvement). The following have been added to the operational DOI:

1. Zonal harmonics – Kozai's theory for long-period and secular perturbations due to J_2 terms in the earth's gravitational field.

2. Tesseral harmonic perturbations due to tesseral harmonics of the earth's potential.

3. Lunar perturbations.

4. MAR, which will compute precise mean-anomaly residuals for each observation with respect to the input orbit.

5. SLOI, which corrects the mean motion for contributions to the motion of the argument of perigee that arise from sources other than the earth's gravity and that are reflected in the mean motion. This correction is necessary in some cases in order that the semimajor axis, which is computed from the mean anomaly, be accurately determined. For satellites with large area-mass ratios (one of the balloon satellites, for example), solar-radiation pressure may produce a linear term in the argument of perigeė of equal or greater magnitude than that due to gravity. In such a case, SLOI will produce much better orbits from photoreduced observations and will probably yield significant improvement even with field-reduced observations.

AIMLASR. This laser prediction program is now operational. It has been expanded to include the option of output on paper tape for direct transmission to the laser sites via teletype transmission.

Doppler data. Two programs have been written for converting range and range-rate Doppler observations of satellites into a format acceptable to DOI.

ASIRP. This new reduction program has been put into production. It replaces SI-ARP and SI-PREP and uses an automatic star-identification facility.

Ephemeris package. About 80% of the computational subroutines and 70% of the main driving program have been completed. This package will replace all other Ephemeris programs with the possible exception of Ephemeris 7. Perhaps the outstanding feature of this new package will be its great flexibility through control cards. This flexibility will include the possibility of generating new types of ephemerides by this package by proper arangement of control-card configuration.

Miscellaneous. The following programs have also been completed:

1. A program for computing second-order short-period perturbations due to the earth's oblateness.

2. A program for the inversion of matrices of practically unlimited size.

3. A CDC 6400 program to manipulate Poisson series.

4. A program to compute the secular variations of the orbital elements for a direct orbit whose aphelion is within the orbit of the disturbing planet.

5. Programs for handling various aspects of orbit computation of comets.

DATA UTILIZATION

RESEARCH AND ANALYSIS

Dynamical and Geometrical Geodesy and Geopotential Investigations

Mr. E. M. Gaposchkin directed the preparation of computer programs that are instrumental in the dynamical geopotential calculation of the 1968 Smithsonian Standard Earth. Most of the existing programs have now been rewritten for the new computer; however, the reformulation of theoretical foundations to bring all accuracies to 1/2 m necessitated a continuing programming effort. Existing perturbations used in orbit calculations that were rewritten are second-order oblateness, lunar perturbations, and tesseral harmonics. The refinements now in various stages of development are short-period perturbations due to atmospheric drag, long-period atmospheric drag, solar-radiation pressure, and long-period zonal perturbations.

The 1968 Smithsonian Standard Earth will utilize data from various tracking systems. Mr. L. H. Solomon worked on the conversion of NASA range and range-rate tracking data to a format usable with the SAO orbit-determination programs and tracking data. This includes the evaluation and correction of tropospheric and ionospheric contributions to the system errors and an analysis of system accuracy relative to the SAO tracking systems. Preliminary results were reported at the AGU meeting in April 1967 and at a NASA working group meeting in May. Work is continuing on this system, which has been expanded to include Minitrack, SECOR, APL Doppler, and other precise tracking systems.

In preparation for utilizing large quantities of diverse tracking data, Mr. Gaposchkin and Mr. Solomon began preparing computer programs for the reduction, handling, and evaluation of data. The 1968 Smithsonian Standard Earth will use a master data file, machine-accessible for all three solutions (geometric, dynamic, and gravimetric).

Some preliminary Standard Earth calculations, mainly regarding initial condition parameters, have been performed. Mr. A. Girnius revised the coordinate-transformation program to an accuracy of 1 cm, because of the prospective higher accuracy in station-position determination with the advent of laser tracking. The geodetic coordinates of the range and range rate, sequential collocation of range (SECOR), Minitrack, and MOTS tracking stations were transformed to the SAO standard system as part of the input to the 1968 Smithsonian Standard Earth calculation, which will begin in the fall of 1967. The coordinates of the earth's instantaneous pole were compiled from 1891.5 to 1967.1, and the plotting program was revised.

For geoid studies, a program for datum rotation, which will complement an older program for datum displacement, was written and checked by hand calculations.

In geometrical geodesy studies, the total number of synthetic simultaneous observation pairs as of June 1, 1967, stands at 3332. Fourteen Baker-Nunn camera stations have been connected by 41 lines. From 3152 synthetic simultaneous observation pairs, Mr. Girnius determined the directions of 32 lines through individual line adjustments and the absolute directions of 25 lines, applying net adjustments according to coplanarity conditions. Through a selection of observational material and by application of stricter criteria for poor observations, much smaller closing discrepancies in the unit-vector triangles between stations were obtained.

Mr. J. Rolff, on behalf of the Observatory and the Central Bureau for Satellite Geodesy, continued his efforts to increase international cooperation in satellite geodesy, primarily concentrating on coordinating the efforts of European scientists. He attended a meeting of the West European Satellite Triangulation Commission in Venice, Italy. He also visited four GEOS observing stations in Western Europe to discuss operational and scientific matters. As a result, hundreds of GEOS flash observations received from these stations can now be incorporated into Observatory geodesy programs. Cooperation with the East European sector continues to be excellent. Riga, USSR, sent in its first precisely reduced GEOS observations.

Dr. W. Köhnlein derived the gravity gradient on the earth's surface from the motion of artificial satellites. The anomalous effect (referred to an ellipsoidal field) shows a strong correlation with the continental topography: positive values in flat areas and negative anomalies in areas coinciding with the worldwide mountain chains. The gravitational potential has been determined from a combination of satellite data with free-air gravity anomalies. To date, the harmonic coefficients are analyzed up to degree and order 12, including certain higher resonant terms such as 15, 13; 15, 14.

In an attempt to improve the accuracy of available direction observations, Dr. B. Kolaczek studied the technique of observing star occultations by satellites. This photoelectric tracking system could conceivably track bright or dark satellites with the observed time of a star occultation by a satellite giving directly accurate topocentric satellite positions. The system accuracy should be of the order of the star-position accuracy, in general, better than the Baker-Nunn camera accuracy.

Dr. Kolaczek and Mr. C. G. Lehr estimated the frequency of occurrence of star-satellite occultations, and the first observational experiments began with the cooperation of Wright-Patterson AFB.

Atmospheric Studies

Dr. L. G. Jacchia and Mr. J. W. Slowey continued to derive atmospheric densities from the orbital drag of a number of satellites and to use them to investigate the structure and variations of the upper atmosphere. It is expected that a "catalog" of densities not previously published will appear soon. They are now using all the accumulated data in a series of studies of the several types of variation. A study of atmospheric disturbances associated with geomagnetic activity was completed earlier; now a detailed study of the diurnal variation has been completed. Contrary to some recent suggestions, they found that the diurnal bulge does migrate seasonally with the sun and that it has a shape similar to that in earlier models. The disparity in high latitudes that had led to a revision in the shape and location of the bulge was explained in terms of an independent density bulge that forms over the geographic pole in either hemisphere during the winter months. This work made use of Satellites 1958 Alpha, 1959 α1, 1960 ξ1, 1962 βτ2, 1963 ι1, 1963 53A, 1964 76A, and 1964 84A.

Similar studies of the semiannual variation and the solar-cycle variation are in progress. A study of the atmospheric perturbations associated with selected major geomagnetic perturbations has also begun, with photoreduced observations being used where possible. Mr. Campbell is assisting in this and other work.

Dr. Jacchia and Mr. Slowey have analyzed the drag on Echo 2 over a long interval and have nearly completed work on a similar interval for 1963 30D. Both satellites have great perigee heights and are strongly affected by solar-radiation pressure. The discovery by Mr. Slowey of the necessity of correcting the mean motion for the effects of solar-radiation pressure has made it possible to compute much more accurate orbits for these objects and has greatly increased the reliability of the density data obtained from them.

Dr. M. Roemer visited the Observatory for several weeks. With the help of the group here, he is continuing work on the drag analysis of the Echo-1 satellite that he began earlier.

Dr. M. P. Friedman set up for solution on the digital computer a theoretical description of the behavior of the upper atmosphere. With this, SAO can determine the atmospheric temperature and density at points all around the globe between altitudes 120 and 1000 km. In this altitude range the various constituents of the atmosphere separate, the lighter ones rising more rapidly. In his analysis the major neutral constituents O_2, N_2, O, He, and H are considered.

Although this altitude range includes the ionosphere, the charged particles are at much lower concentration than the neutrals. The electrons have a small but measurable effect on the temperature of the neutral constituents, as the electrons are somewhat hotter. The main source of heat is, however, solar radiation. Dr. Friedman's initial results give atmospheric temperatures and densities that agree reasonably well with satellite measurements.

Dr. Papaliolios continued to try to determine the lifetime of the $a^3\pi$ state of CO by high-resolution spectroscopy. A hydrogen continuum source was built for this purpose, and the absorption band at 2064 Å was seen with a low-resolution instrument.

Laser Investigations

The laser system at the observing station in New Mexico continued the measurement of ranges to satellites. Since its installation in 1965, about 2000 range observations have been obtained with the system. Some of these observations have been used along with precisely reduced Baker-Nunn observations in the computation of orbits. These computations show that the laser range measurements are consistent with the angular measurements obtained with the cameras.

The number of photons in the received laser pulse was measured for 17% of the returns. These data are being used for Mr. Lehr's statistical analysis of such effects as velocity aberration, atmospheric transparency, and diffraction of the retroreflector.

Celestial Mechanics

Dr. S. E. Hamid has undertaken a program of identification of old Chinese observations of comets with currently observed comets. In order to check the validity of his development of the disturbing function and the numerical approach to the secular perturbation of bodies within the solar system, a project to obtain the ephemerides of Comet Encke for the last 2500 years was begun. In an attempt to identify Encke's Comet with old Chinese observations, about 13 observations from as early as 110 B.C. were found to agree with the predicted position of Comet Encke. To confirm these findings, the effects of short- and long-periodic perturbations of the planets on Comet Encke must be considered. This requires the construction of tables giving the position within the solar system of the planets in the past 2500 years.

Dr. Hamid is in the process of constructing these tables using the theories of Newcomb, Leverrier, and Clemence. Physical forces affecting the comets should be detected through the comparison of the observed positions with the predicted positions.

Dr. Hamid has also generalized and programmed for computer development Brouwer's approach to the computation of the secular perturbation of direct short-periodic orbits. The computer program enables Brouwer's approach to be carried out to any order of magnitude. He applied the complete analytical solution of the problems given by Brouwer to different orbits with the sizes, shapes, and orientations that initially intersected the earth.

Some of these orbits are found no longer to intersect the earth. Also, for those orbits that do intersect, it was found that their inclinations at the point of intersection differ from the initial inclination. These findings are contrary to the initial assumptions underlying Öpik's and Arnold's work in their Monte Carlo studies of the origin of meteorites, asteroids, and meteors. The effect of secular perturbations should be considered in studying the evolution of these bodies.

Dr. B. G. Marsden's orbit-computation programs are essentially complete. It is now possible to discuss observations of a comet or asteroid made over an indefinite period of time, and to include the effects of the perturbations by all the major planets. The programs have been applied to link the observations at two consecutive apparitions of a few comets. Orbits and ephemerides have been calculated for several recently reported comets and asteroids. An attempt is currently being made to fit the observations of periodic Comet Pons-Winnecke, using photographic observations made between 1927 and 1964. The principal reason for doing this is to investigate the nongravitational forces that may be acting. This comet is well suited for this study because of its very close approaches to the earth and the consequent high sensitivity of the observations. Schemes have been devised for predicting occultations of radio sources by comet tails, and also for calculating the directions from the earth to the tangents to the orbits of a number of comets, in the hope that a concentration of cometary material might be observable there. A rather approximate calculation regarding Halley's Comet indicates that the mass of Whipple's proposed comet belt outside the orbit of Neptune must be very small.

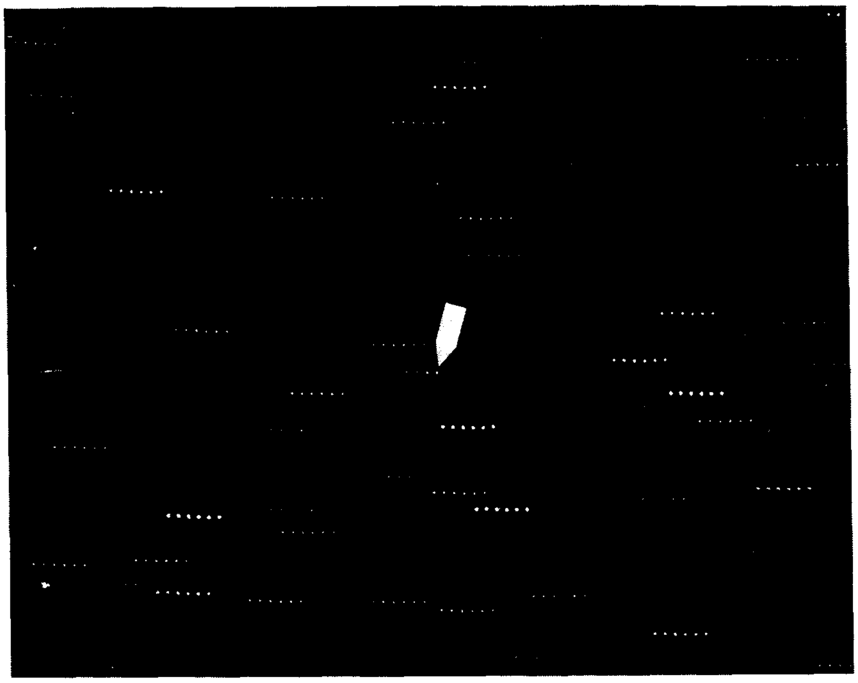
Dr. Kolaczek has prepared for publication a review of the selenocentric spherical coordinate systems in conjunction with related problems such as the influence of the moon's precession and rotation, and the transformation of the moon's monthly aberration into these coordinates. This coordinate system will permit consideration of the space positions of the celestial bodies from the surface of the moon.

Flare-Star Investigations

Mr. Solomon has continued research in flare stars in conjunction with the Jodrell Bank, England, and CSIRO, Australia, radio telescopes. A total of 49 hours of mutual observing was accomplished with these instruments and with several of the Baker-Nunn cameras. In addition, 98 hours of data from previous observing periods were reduced. A new method of reduction using a microdensitometer was tested for multiply exposed film. The results seem to be good (see Figure 5 for a plot of the resultant light curve). Mr. Solomon plans to reduce all identified flares by this procedure. A compendium of charts and a bibliography of flare stars are being prepared for publication; the major delay has been in obtaining good photometric observations of the comparison star sequences.

Mr. Solomon has also prepared a Special Report compiling results of various photometric work with the Baker-Nunn camera. These results were obtained from preliminary flare-star work, but are applicable to the satellite-tracking problem.

a)



b)

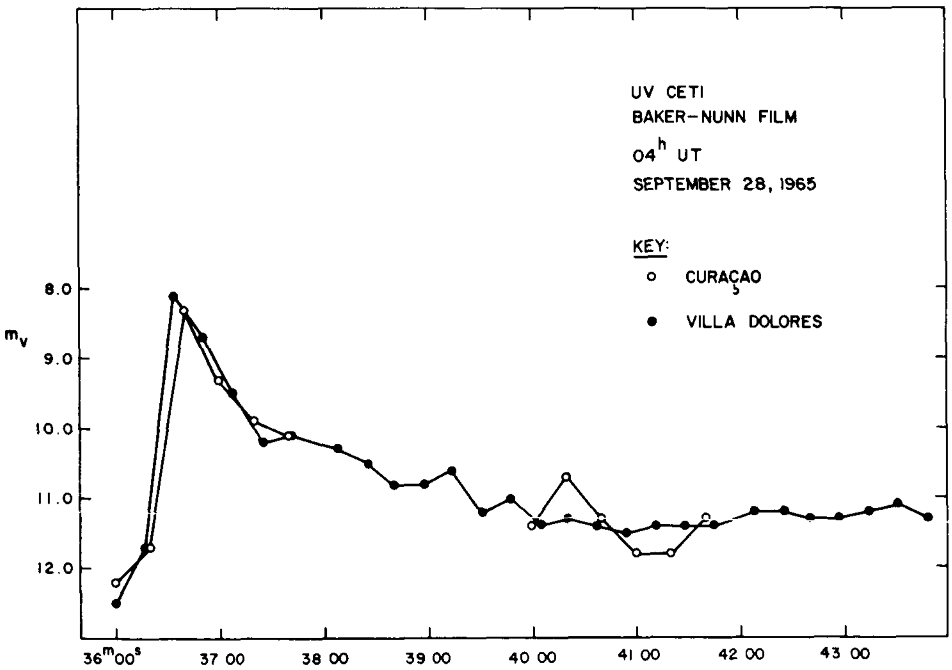


Figure 5. a) Multiply exposed photograph of UV Ceti showing ~ 3.5 mag flare; exposure, 3.8 sec at intervals of 19.2 sec. b) Magnitude of UV Ceti derived from two films taken at time of flare, reduced by use of microdensitometer.

EDITORIAL AND PUBLICATIONS

The Satellite-Tracking Program issued the following Special Reports during this 6-month period:

No. 200 -- Geodetic parameters for a 1960 Smithsonian Institution Standard Earth by C. A. Lundquist and G. Veis (eds.)

No. 236 -- Scientific horizons from satellite tracking by C. A. Lundquist and H. D. Friedman (eds.)

No. 237 -- Baker-Nunn photography of the Intelsat 2-F2 apogee-motor firing by the Staff of SAO

No. 238 -- On the distribution of the Gibeon meteorites of South-West Africa by R. Citron

No. 241 -- Design of a satellite experiment for atmospheric density and near-free-molecule-flow aerodynamics by L. S. Lam, G. M. Mendes, and C. A. Lundquist

No. 242 -- Diurnal and seasonal-latitudinal variations in the upper atmosphere by L. G. Jacchia and J. W. Slowey

No. 243 -- South Africa Baker-Nunn photography of the PAGEOS-A inflation and apogee burn of the Agena D by W. Kirchhoff and J. Latimer